State of the Wind Industry:
Technology, Economics and Future Evolution

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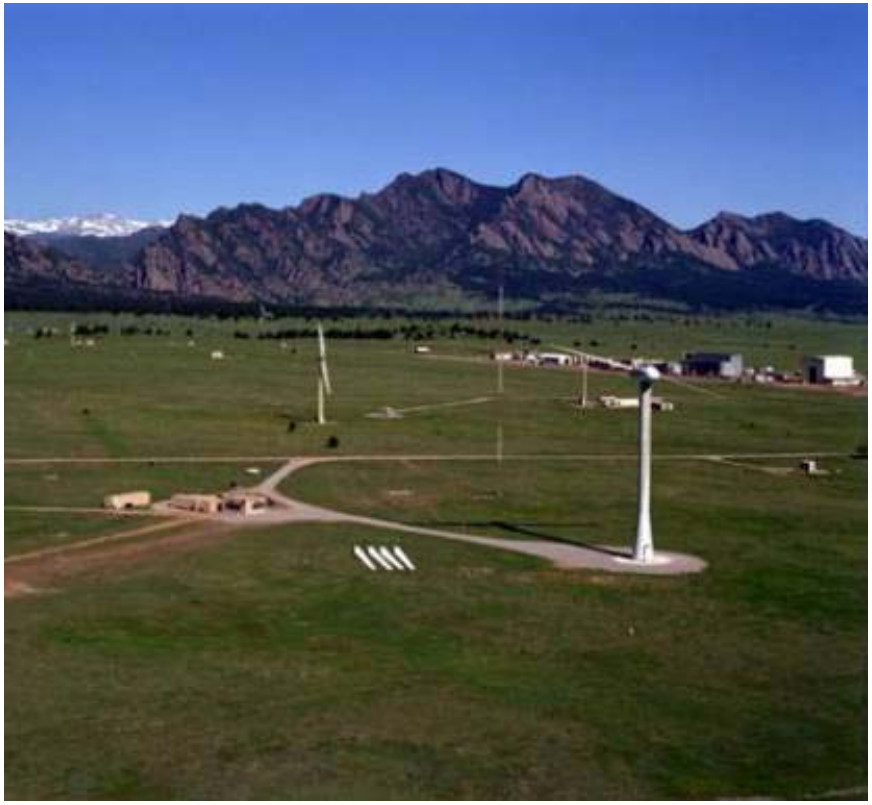
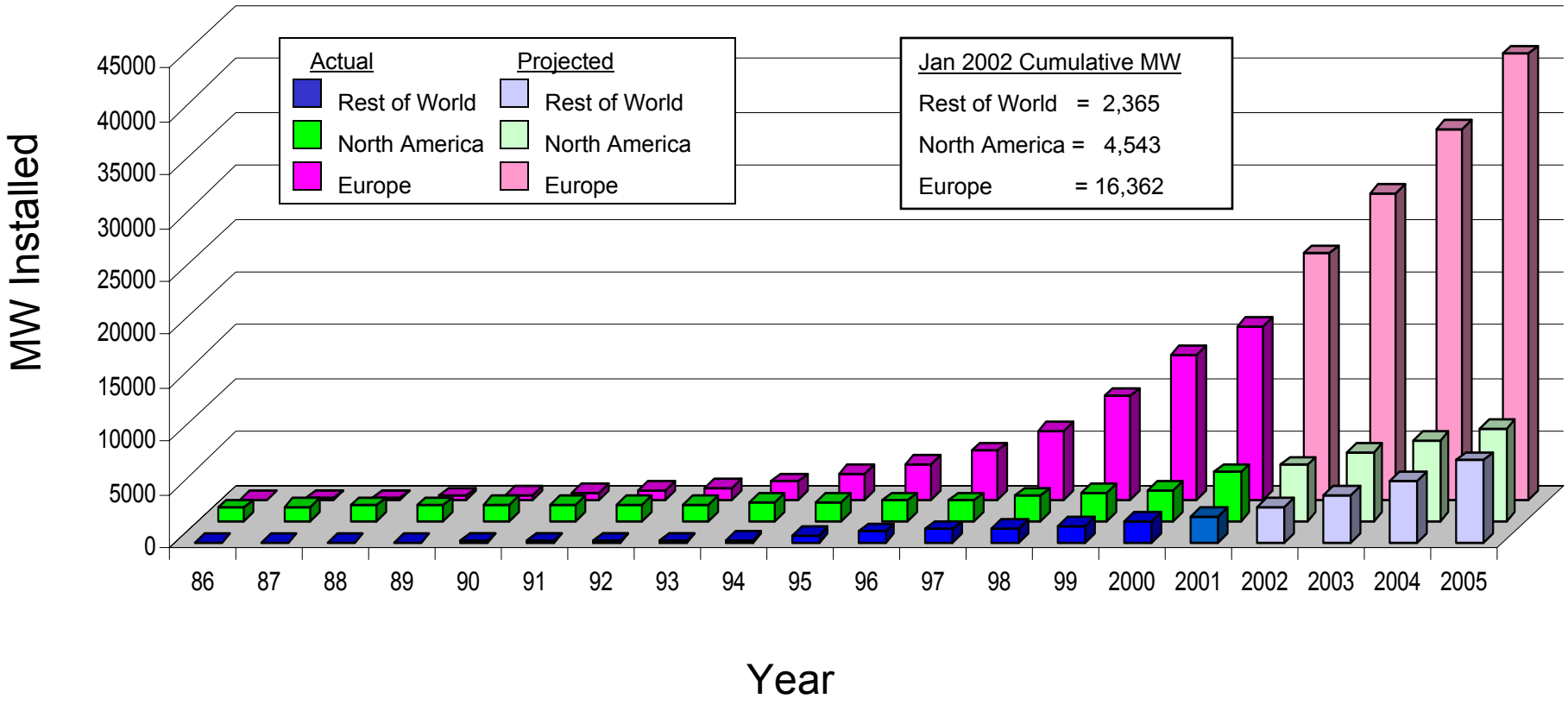


Growth of Wind Energy Capacity Worldwide



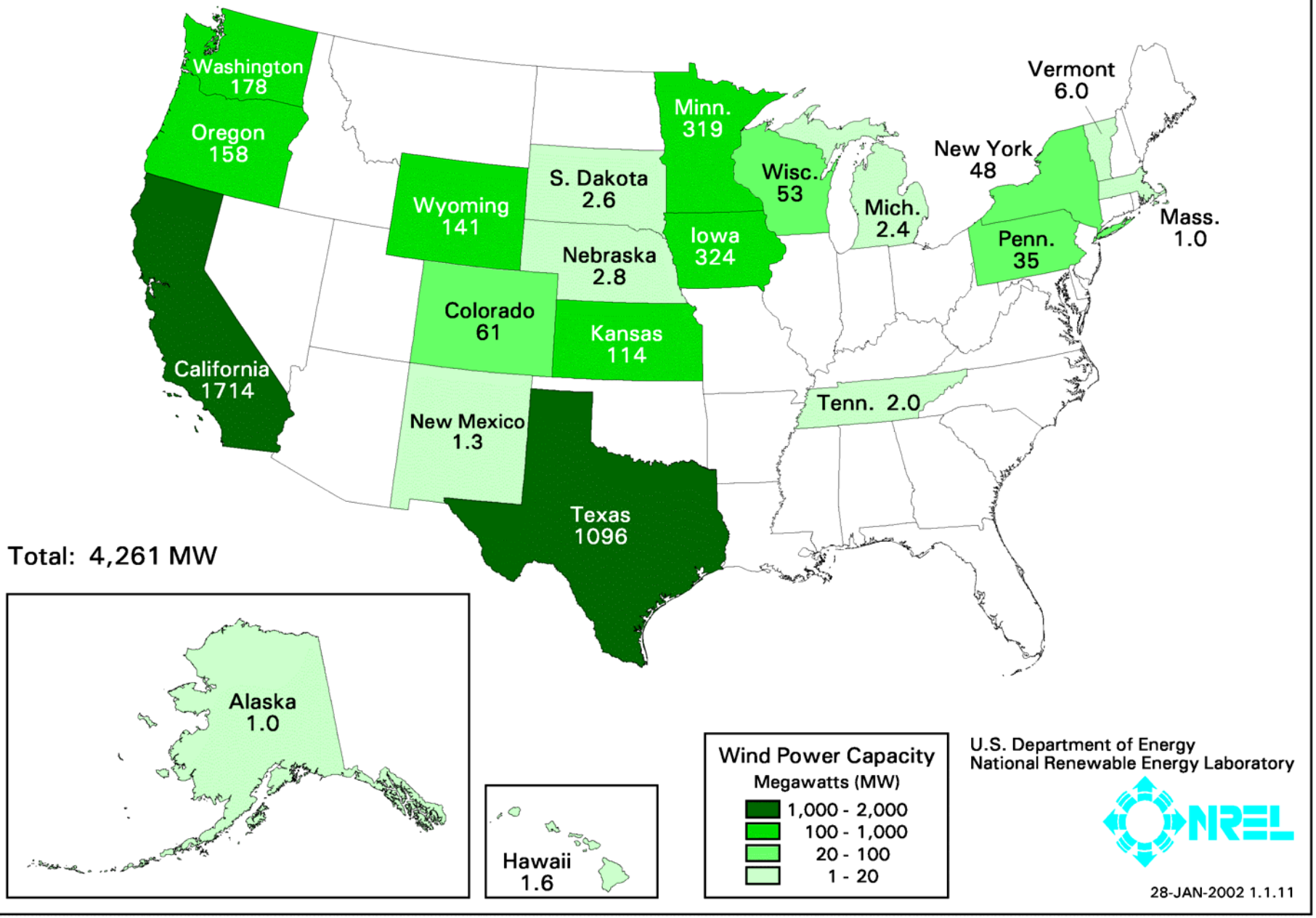
Sources: BTM Consult Aps, March 2001
Windpower Monthly, January 2002

International Market Drivers

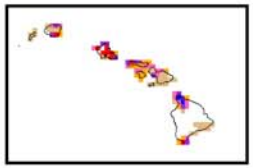
- Europe
  - high mandated purchase rates (85-90% of retail, 10-12 cents/kWh)
  - strong government and public commitment to the environment, including climate change
  - population density & existing developments driving off shore deployment in Europe

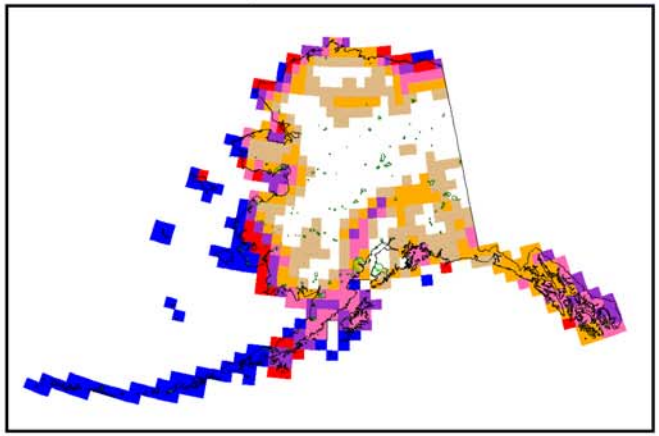
- Developing World
  - huge capacity needs
  - lack of existing infrastructure (grid)
  - pressure for sustainable development (IDB's, climate change)
  - tied aid

United States - 2001 Year End Wind Power Capacity (MW)



United States - Wind Resource Map





Source: "Wind Energy Resource Atlas of the United States", 1987

Indian Reservations and Alaska Native Village Areas

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

U.S. Department of Energy
National Renewable Energy Laboratory

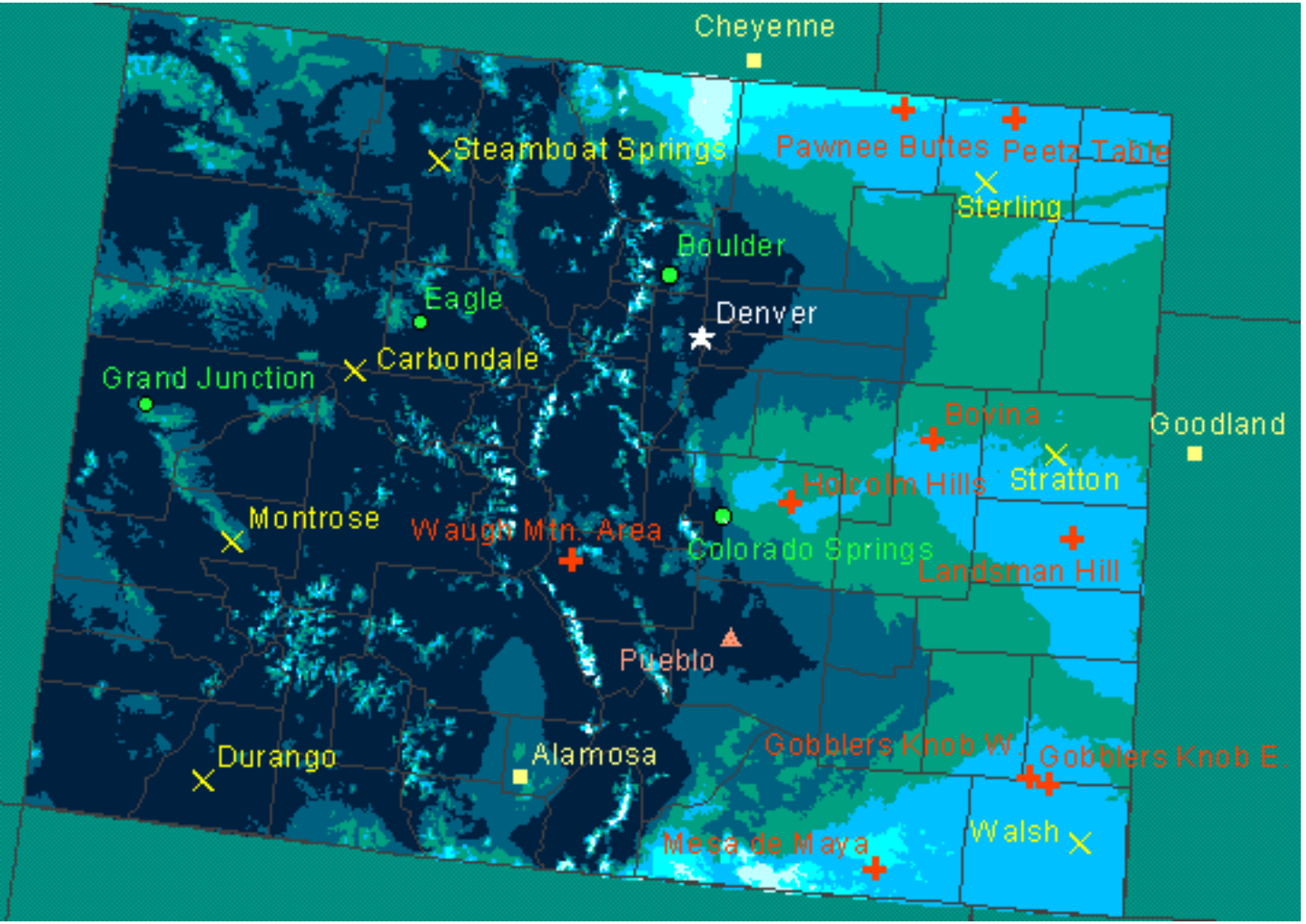
NREL

DM Heimiller 31-MAY-2001 1.2.8

CORRD

Colorado Renewable Resource Database

http://www.coloradoenergy.org/corrd/default.asp



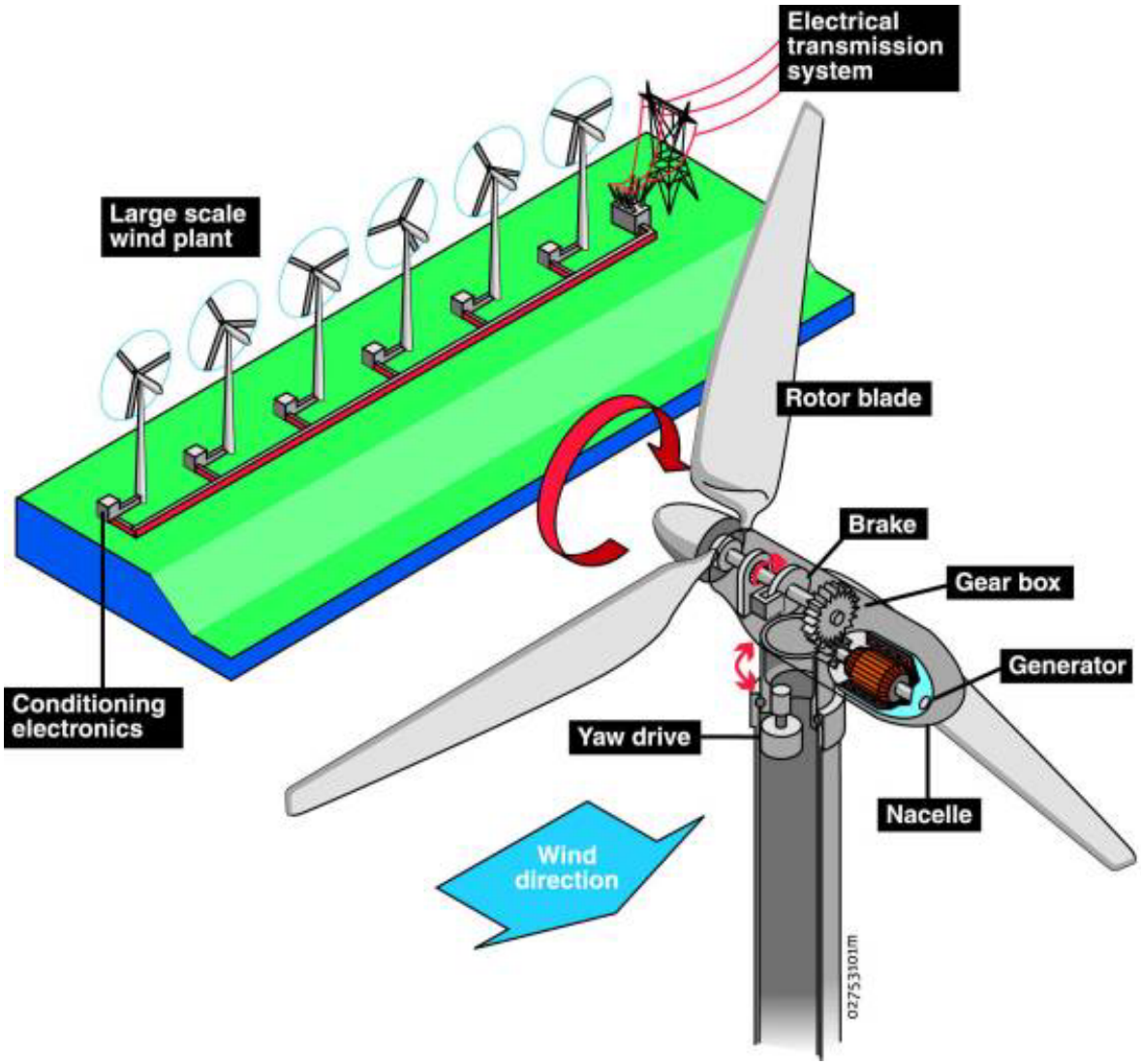
Anemometer height: 10 m	Max. wind power density (W/m^2)	Max. wind speed (m/s)
	100	4.4
	150	5.1
	200	5.6
	250	6.0
	300	6.4
	400	7.0
	1000	9.4

- WEST Associates - Hourly solar, wind and temperature
- WEST Associates and NSRDB - Hourly solar, wind and temperature
- JCEM and NSRDB - Hourly solar, wind and temperature
- NSRDB - Hourly, monthly, and TMY2 solar, wind and temperature
- Public Service Co - Annual average wind speed
- JCEM - hourly solar, wind and temperature

Source: Office of Energy Conservation Utility Wind Resource Assessment (1995)

Wind Energy Technology

At it's simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity. Large turbines can be grouped together to form a wind power plant, which feeds power to the electrical transmission system.



Sizes and Applications

Small (≤10 kW)

- Homes
- Farms
- Remote Applications

(e.g. water pumping, telecom sites, icemaking)

Intermediate (10-250 kW)

- Village Power
- Hybrid Systems
- Distributed Power

Large (250 kW - 2+MW)

- Central Station Wind Farms
- Distributed Power

Cost of Energy Trend

1979: 40 cents/kWh

2000:
4 - 6 cents/kWh

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

2004:
3 - 5 cents/kWh

NSP 107 MW Lake Benton wind farm
4 cents/kWh (unsubsidized)

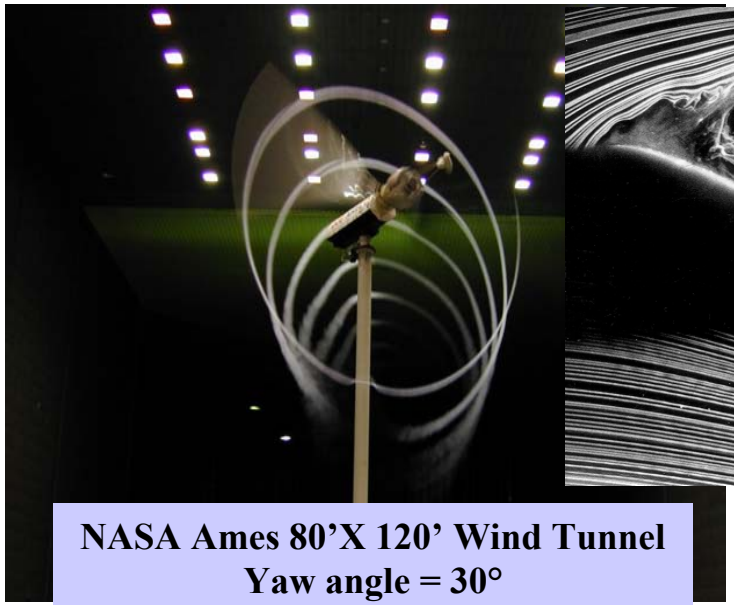
Finances and Incentives

- Production Tax Credit
  - 1.7 cents/kWh (escalating) for 10 years equates to around 1.1 cents/kWh reduction in contract price
  - deadline pressure *increases* costs
- State and Local tax, etc. can be significant
  - +/- 0.5 cents/kWh impact
- Public Power (100% debt at tax free rates)
  - 60% of GenCo or IPP cents/kWh
- Renewable Energy Production Incentive
  - annual appropriations problem leads to little impact

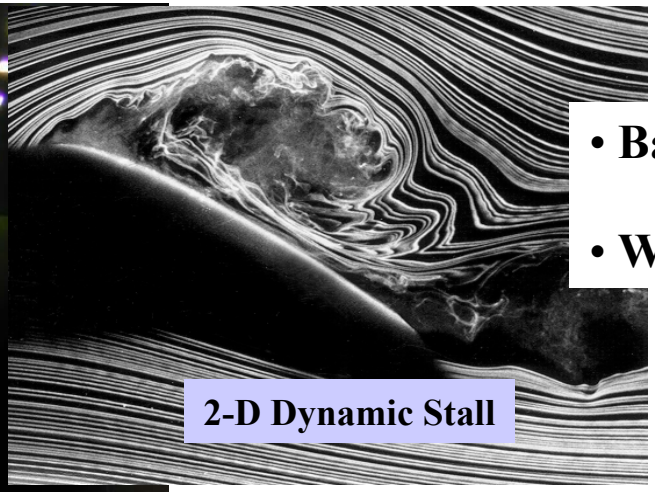
Avian Impacts with Wind Turbines

- Data suggest the most significant avian wind-turbine interaction problem in the U.S. is in the Altamont WRA.
- There is no reason that avian issues should be a concern for future wind farm development; any potential problem should be identified and dealt with before micrositing occurs.
- Two guidance documents have been adopted by the NWCC: (1) *Permitting of Wind Energy Facilities,* and (2) *Metrics and Methods for Avian Studies.*
- Facilities developed following these guidelines have not experienced significant avian impact issues.

NREL's National Wind Technology Center
Research and Development



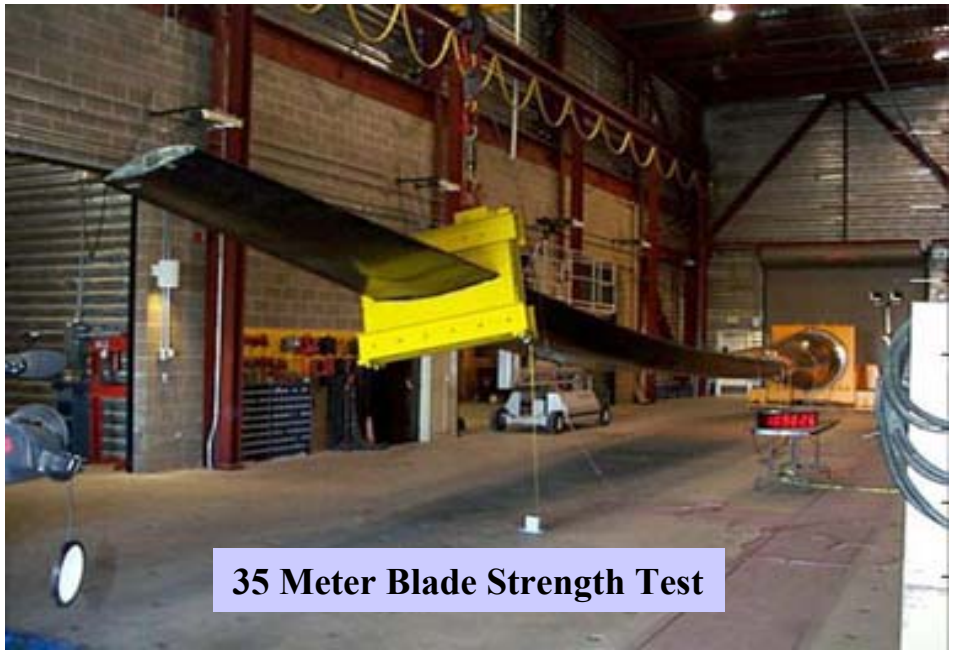
NASA Ames 80'X 120' Wind Tunnel
Yaw angle = 30°



2-D Dynamic Stall

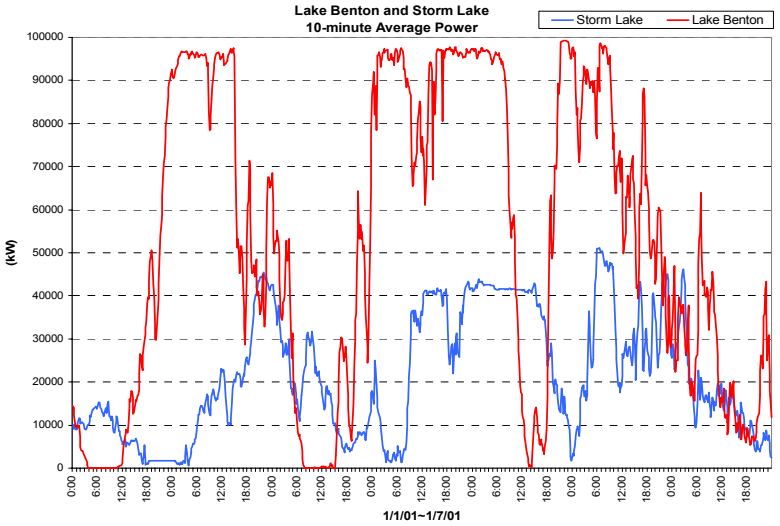
- Basic & Applied Research
- World-Class Testing Facilities

EW 1.5 MW Drive Train



35 Meter Blade Strength Test

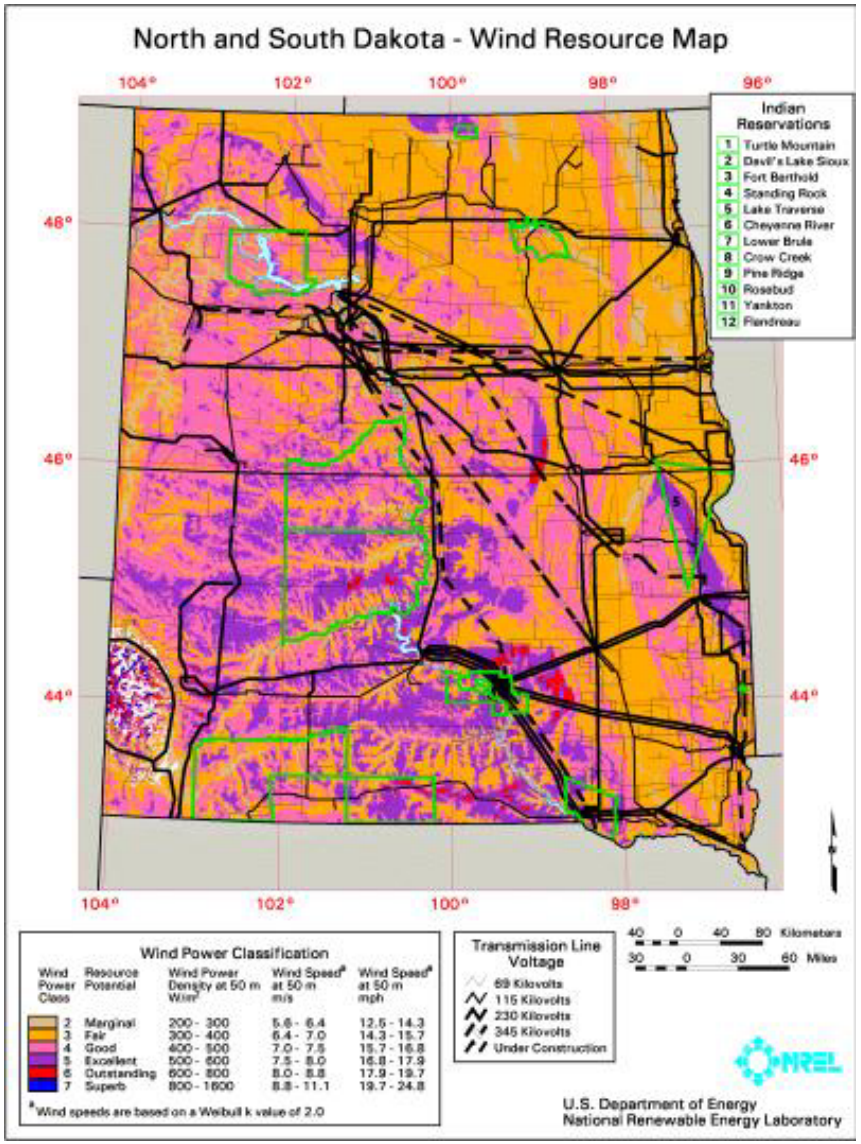
Utility Grid Interaction Measurements at Lake Benton, Minnesota and Storm Lake, Iowa



- NREL's monitoring effort at Lake Benton II entering the second year of operation. More than 150 million data points have been collected.
- Data collection at Storm Lake (MidAmerican Energy's Buena Vista Substation, about 113 MW wind capacity) began in January 2001 by NREL's subcontractor.
- Data collection at Xcel Energy's Buffalo Ridge substation (about 220 MW wind capacity) began in February 2001 by NREL's subcontractor
- Data offers encouraging evidence that accurate wind power forecast is feasible.

Wind Resource Mapping

- Identifies most promising areas for wind energy development
- Employs geographic information system technology to create layers of key information
- Used by state energy planners, Indian tribes, and developers
- Approach changing from empirical to numerical modeling techniques
- Forecasting, resource assessment and site specific inflow quantification methods are likely to converge into a single approach



The Challenging DOE Program Goals

Low Wind Speed Technology

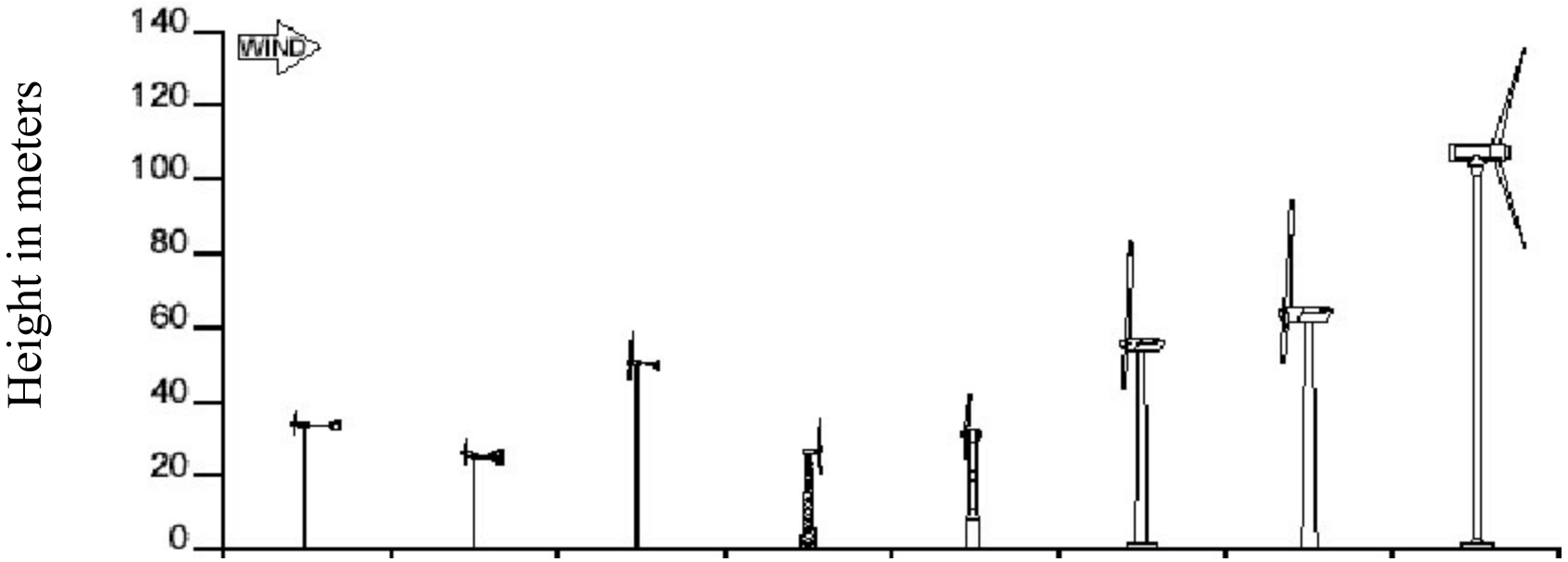
Develop wind turbine technology (>100kW) capable of 3 cents/kWh in Class 4 (13.4 mph wind site) by 2010

- **Increase area available for wind energy development by a factor of 20 or more**
- **Accelerate achievement of the domestic renewable energy generations capacity goal**

Distributed Wind Systems

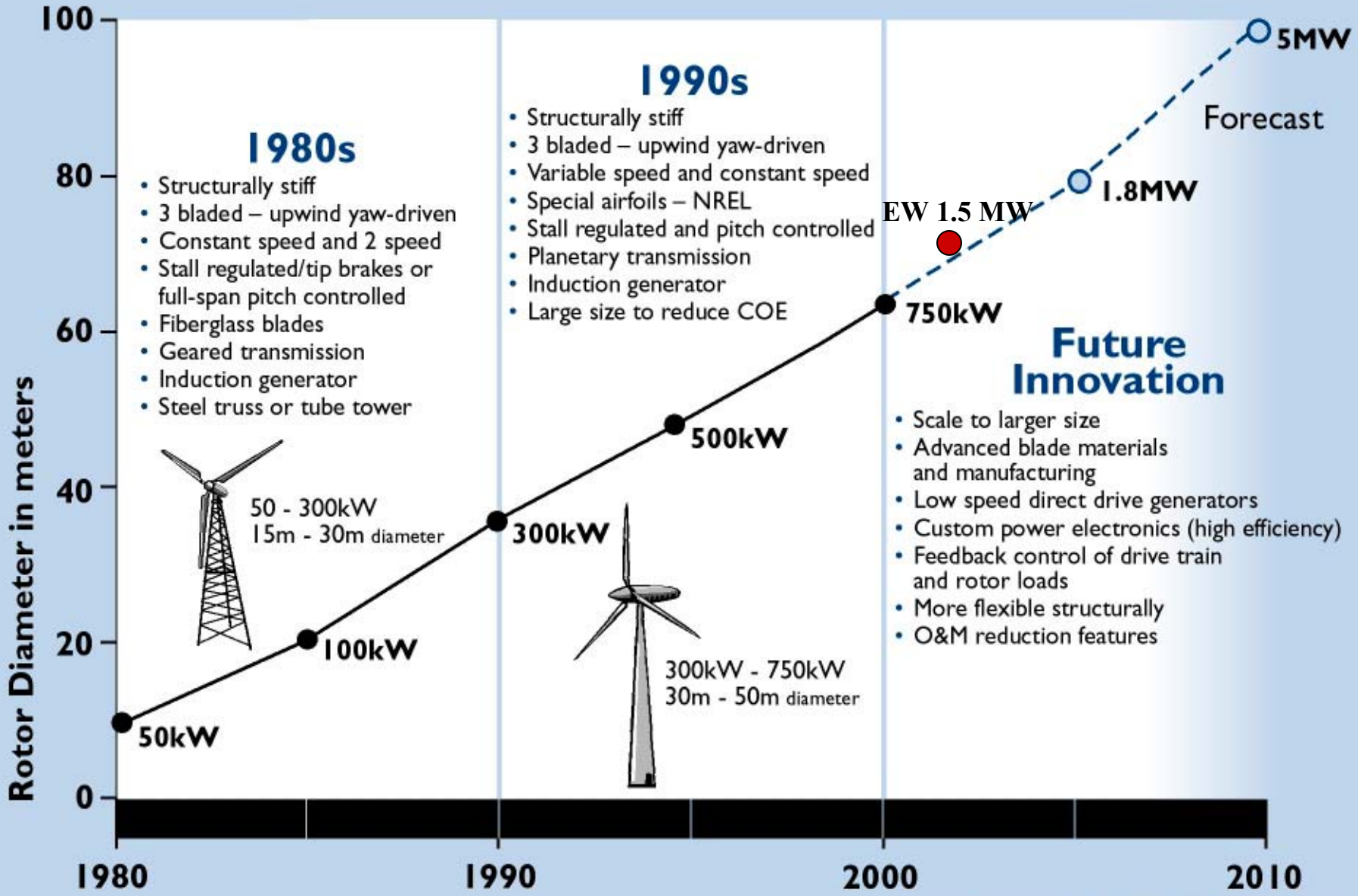
- Reduce the cost of energy from distributed wind systems to $.10-$.15/kWh at Class 3 wind sites (12 mph wind site) by 2007
  - **Increase distributed energy capacity in the United States**

Turbines Under Development with Industry



	WindLite Corporation	Southwest WindPower	Bergey Windpower	Atlantic Orient Corporation	Northern Power Systems	Enron Wind Corporation	Enron Wind Corporation	Wind Turbine Company
Rated Power (kW)	10	5	50	50	100	750	1500	750
Rotor Diameter (m)	7	5	14	15	19	50	77	55
Number of Blades	3	3	3	3	3	3	3	2
Prototype Year	2002	2002	2001	1999	2001	1999	2002	2001

The Evolution of Commercial U.S. Wind Technology



Source: Thresher & Dodge, Wind Energy Journal 1998

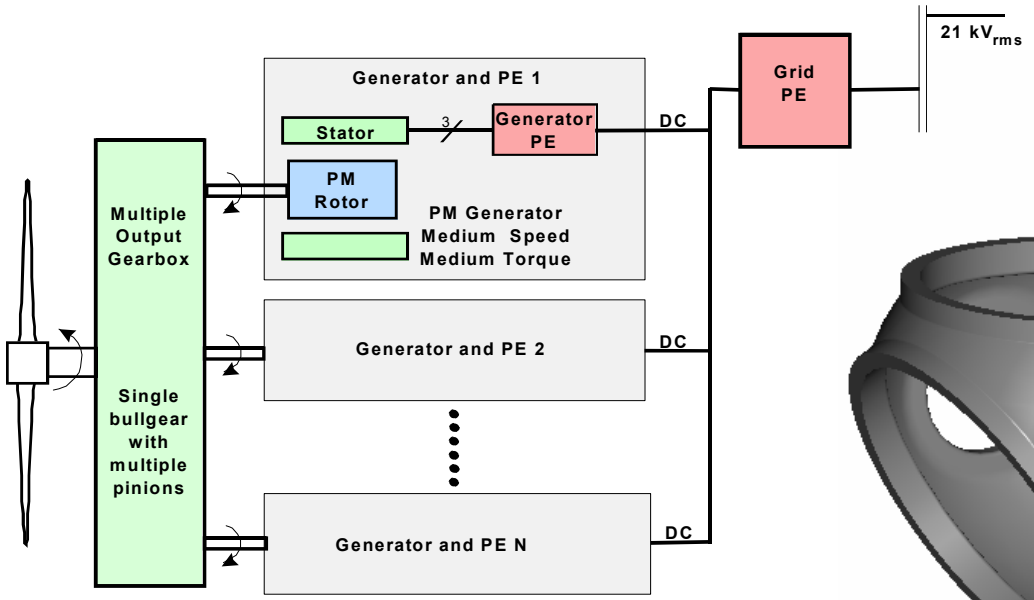
Low Wind Speed Technology Development

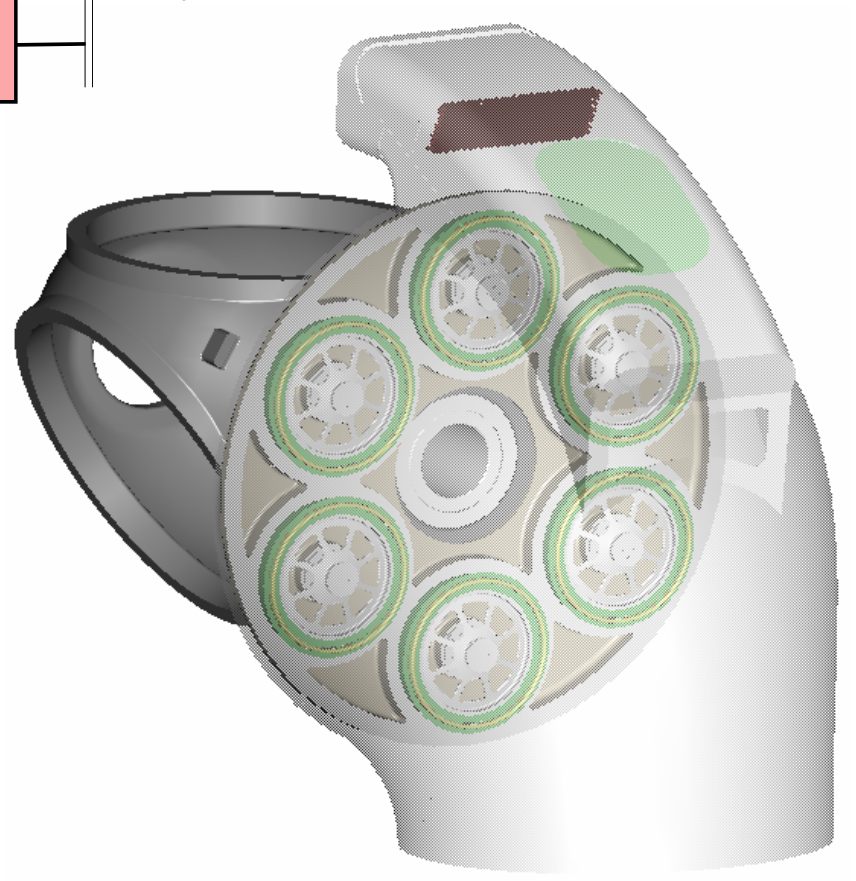
- Low Wind Speed Technology solicitation for $30M in Industry Partnerships over the next four years:
  - Concept Studies; $100K-200K and no cost sharing
  - Advanced Component Development; 30% cost sharing
  - Advanced Systems Development; 30% cost sharing
- Expected Technology Areas for Development
  - Larger-Scale 2 to 5 MW with rotor diameters to 120 meters
  - Innovative rotor designs pushing the technology:
    - ✓ Flexible, low solidity high tip speeds
    - ✓ Expandable rotor concepts
    - ✓ Wind feed forward and load feedback controls
    - ✓ Hybrid E-glass – Carbon composites
  - Innovative lower-cost drive trains
  - Towers of novel design 85 to 120 meters tall

A Low Wind Speed Drive Train Concept :

Multi-Permanent Magnet Generator Concept

Multi-PM Generator with Single Stage Integrated Gearbox





Wind Energy:
A Maturing Technology with a Bright Future

WTC 500 kW Prototype
Mojave, CA

Enron Wind 1.5 MW Turbines
Indian Mesa, TX

Current Status of Wind Technology:

- Wind Technology has matured over 25 Years
- Availability now reported at 98-99%
- Certification to international standards for new turbine designs helps avoid "major failures"
- Current designs produce electricity for 4-6 cents/kWh at Class 6 wind sites (15 mph or higher average wind)

Low Wind Speed Technology Innovations for the future:

- Larger-scale 2 to 5 MW, with rotors diameters to 120 meters
- Flexible, thin high-speed rotors
- Extendable rotor concepts
- Hybrid glass-carbon rotors
- Load feedback control systems
- Custom designed low-speed, permanent-magnet generators
- Self-erecting tall tower designs, 85 to 100 meters tall
- Offshore wind turbines